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13. ABSTRACT *(Maximum 200 Words)*

The optimal source depth for transarctic transmissions and acoustic thermometry over transarctic paths, depends on the sound speed profile at the transmitting site. Furthermore, for analysis and interpretation of acoustic data in the experiment, it is necessary to have information on long-term variations of the sound speed profile in the vicinity of the source. Such variations, like seasonal changes, tidal and internal waves, and intrusions, disturb the modal eigenfunctions and hence the excitation coefficients, which can lead to considerable fluctuations in the modal amplitudes at the receiving site. If these fluctuations are considerable, they may complicate the detection of climatic changes in the mean ice thickness reflected in variations of the sound speed also lead to variations in the modal propagation times, which produce noise in the measurements of climate and basin-scale changes in Arctic water.

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HYDROLOGIC CONDITIONS IN THE SANTA ANNA AND FRANZ VICTORIA TROUGHS

PROGRESS REPORT

Subcontract NO. 4500033228

A.N. Gavrilov
and
S.V Pisarev

MSIC Report No. 4/96

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INTRODUCTION

According to the Science Plan approved by the Joint U.S.-Russian Scientific Sub-Working Group on Scientific and Technical Cooperation in Acoustic Thermometry of Ocean Climate [1], an autonomous acoustic source for starting year-round transmissions across the Arctic Ocean to a receiving array in the Lincoln sea is proposed for deployment in either the northern part of the Santa Anna Trough (Strait), east of Franz Josef Land (FJL), or in the northern part of the Franz Victoria Trough (Strait) west of FJL. The final choice of the source location will depend on the method and instrumentation accepted for the installation of the emitting system.

The optimal source depth for transarctic transmissions and acoustic thermometry over transarctic paths, depends on the sound speed profile at the transmitting site. Furthermore, for analysis and interpretation of acoustic data in the experiment, it is necessary to have information on long-term variations of the sound speed profile in the vicinity of the source. Such variations, like seasonal changes, tidal and internal waves, and intrusions, disturb the modal eigenfunctions and hence the excitation coefficients. which can lead to considerable fluctuations in the modal amplitudes at the receiving site. If these fluctuations are considerable, they may complicate the detection of climatic changes in the mean ice thickness reflected in variations of the modal propagation loss and amplitudes at the receiving site. Local variations of the sound speed also lead to variations in the modal propagation times, which produce noise in the measurements of climate and basin-scale changes in the Arctic water.

In this Progress Report we consider the data on water temperature and salinity from various Arctic data bases, to analyze long-term variations of the sound speed expected in the St. Anna and Franz Victoria Troughs.

II. SANTA ANNA TROUGH

2.1. Data

For the analysis we used the following data:

1. Sound speed profiles from the World Ocean Atlas WOA-94 which are located within 80-85° N and 64-76° E. All of these profiles have been tested for possible errors and then 4 profiles have been excluded from further analysis. Finally, 20 profiles were accepted for analysis.
2. 7 vertical profiles from the hydrographic section along 80° N in the St. Anna Trough, measured during a scientific cruise (on a ship from the Murmansk Institute of Marine Biology) in August 1995.
3. 11 summer and 11 winter profiles taken from the latest version of the AARI climatology data base.

Figure 1 shows the bathymetry chart of the St. Anna Trough and the location of some particular CTD profiles.

2.2. Results

An overall T-S analysis was carried out for all of the profiles. The temperature and salinity of the water which occupies the most volume in the layer specified for the standard depths, were chosen as typical. Extreme values were also determined from the T-S diagrams. Figures 2-5 demonstrate examples of those diagrams for the most prominent layers (the upper mixed water, halocline, thermocline, and Atlantic water core).

To study spatial variations in the oceanographic fields in the St. Anna Trough, we drew out vertical sections of the temperature field in both meridional and latitudinal directions. These sections, obtained from the climatology data and the data of 1965 and 1995, are shown in Figures 6 - 11. When looking at these plots, one should note, that the section of 1995 differs considerably from those of the climatology data and the data from 1965. The Atlantic water in the St. Anna Trough, in 1995, was found to be much warmer than in the 1960's and 70's (climatology data). This might be due to the recent intrusion of the warmer Atlantic water into the Arctic Basin detected by several scientists during the 1990s [2-4].

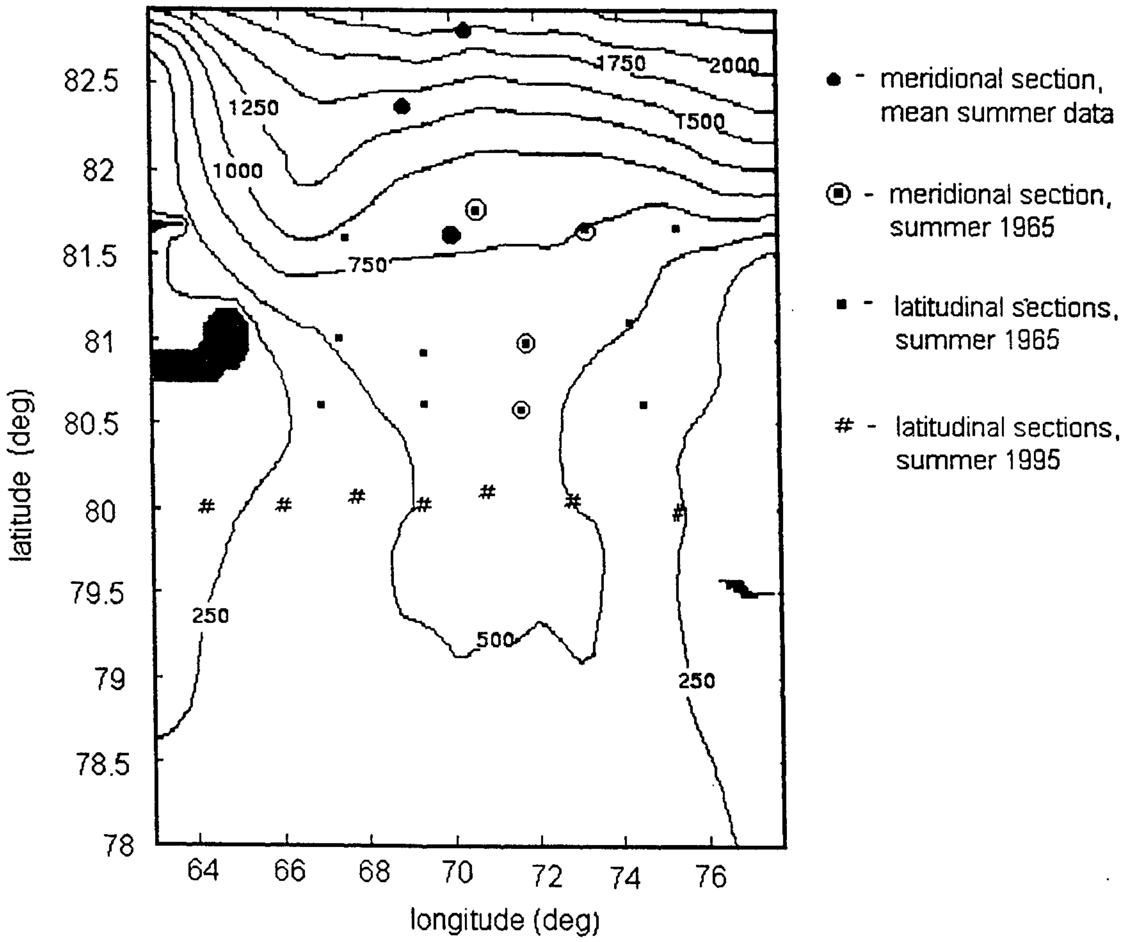

Fig. 1. The bathymetry chart of the St. Anna Trough and the location of particular CTD profiles.

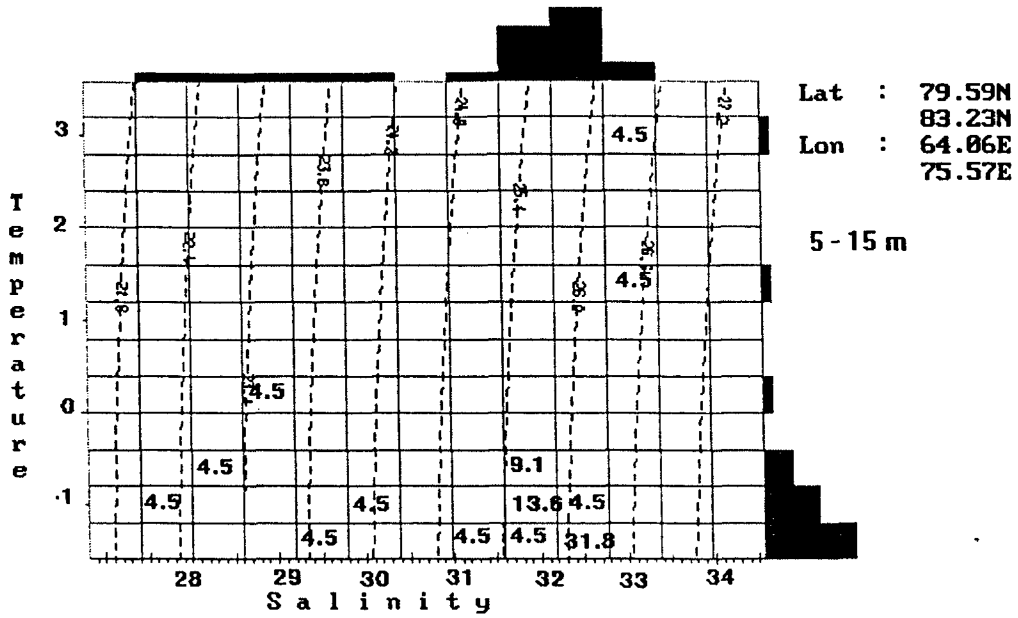

Fig. 2. The T-S diagram for the water layer 5-15 m.

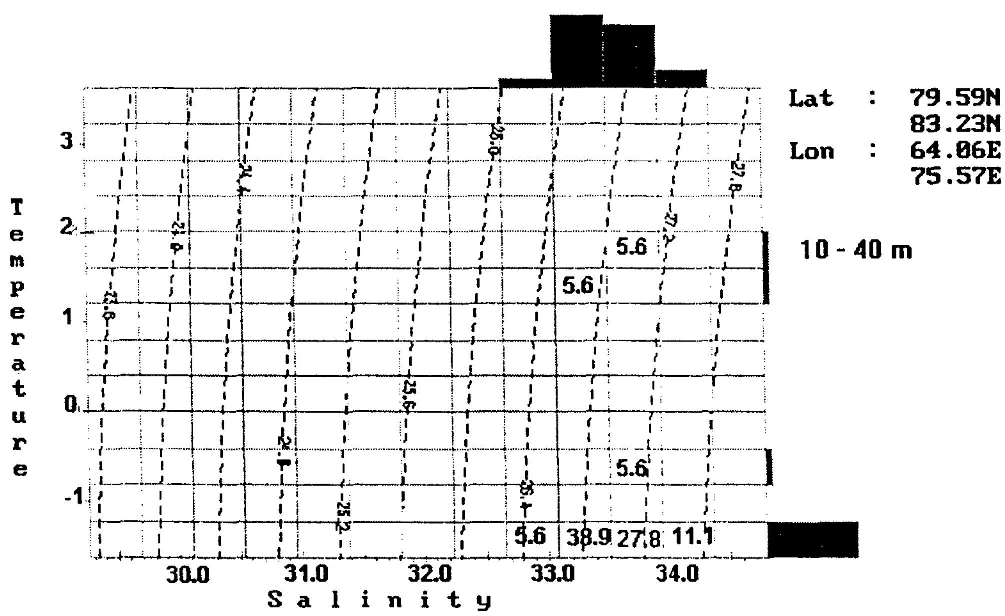

Fig. 3. The T-S diagram for the water layer 10-40 m.

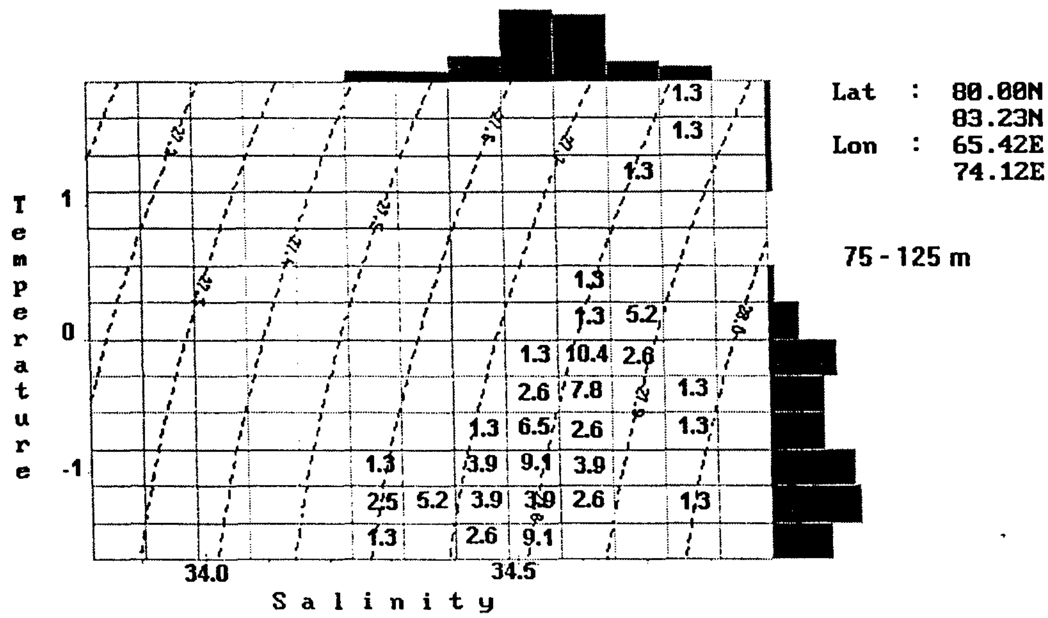

Fig. 4. The T-S diagram for the water layer 75-125 m.

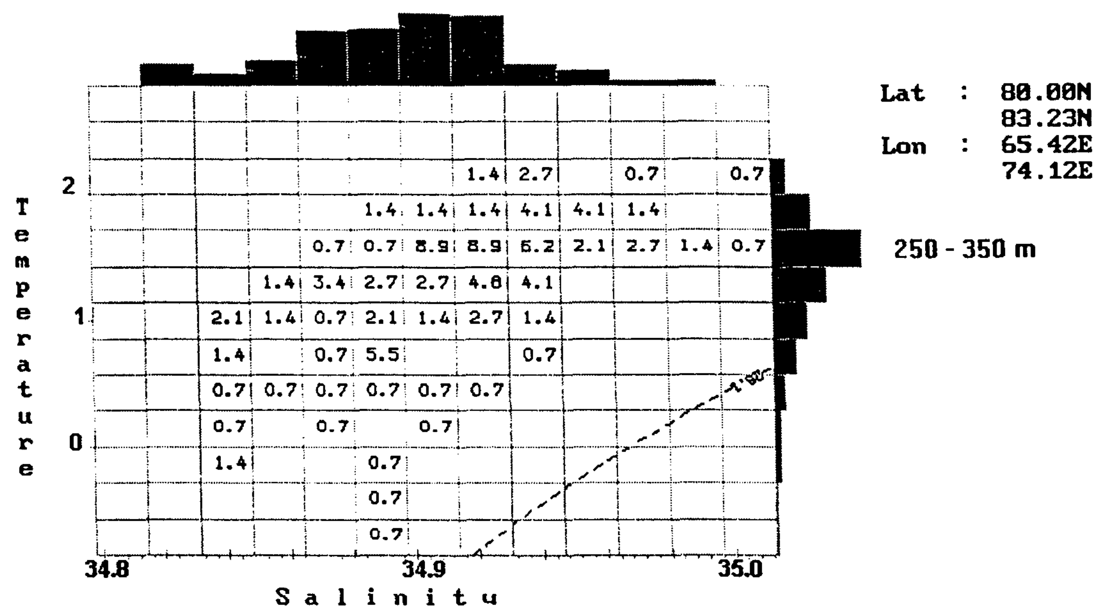

Fig. 5. The T-S diagram for the water layer 250-300 m.

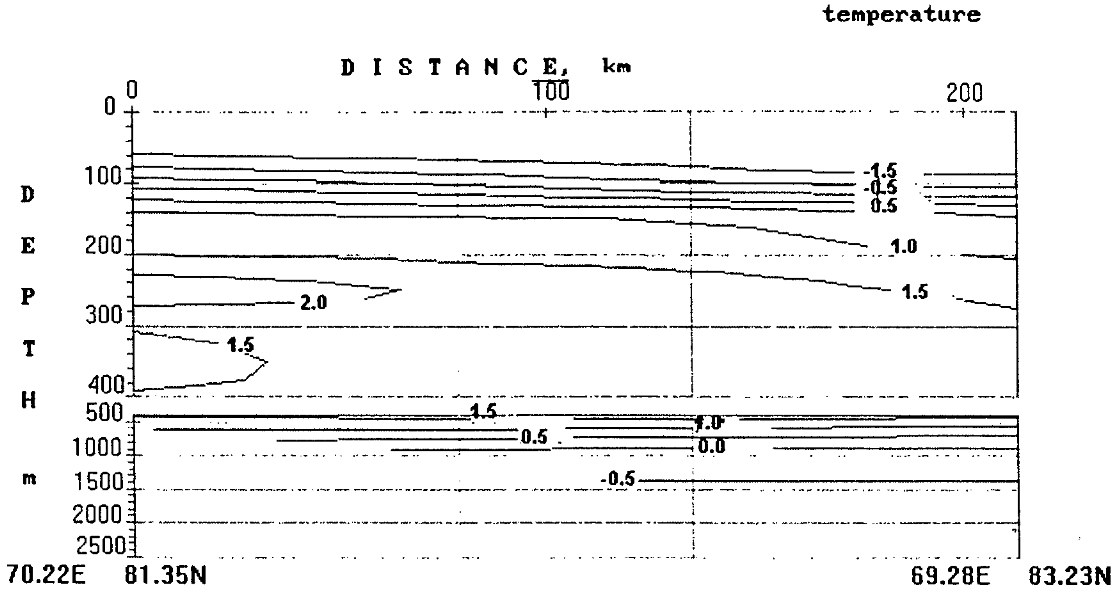

Fig. 6. The summer climatology meridional section of temperature along 70° E.

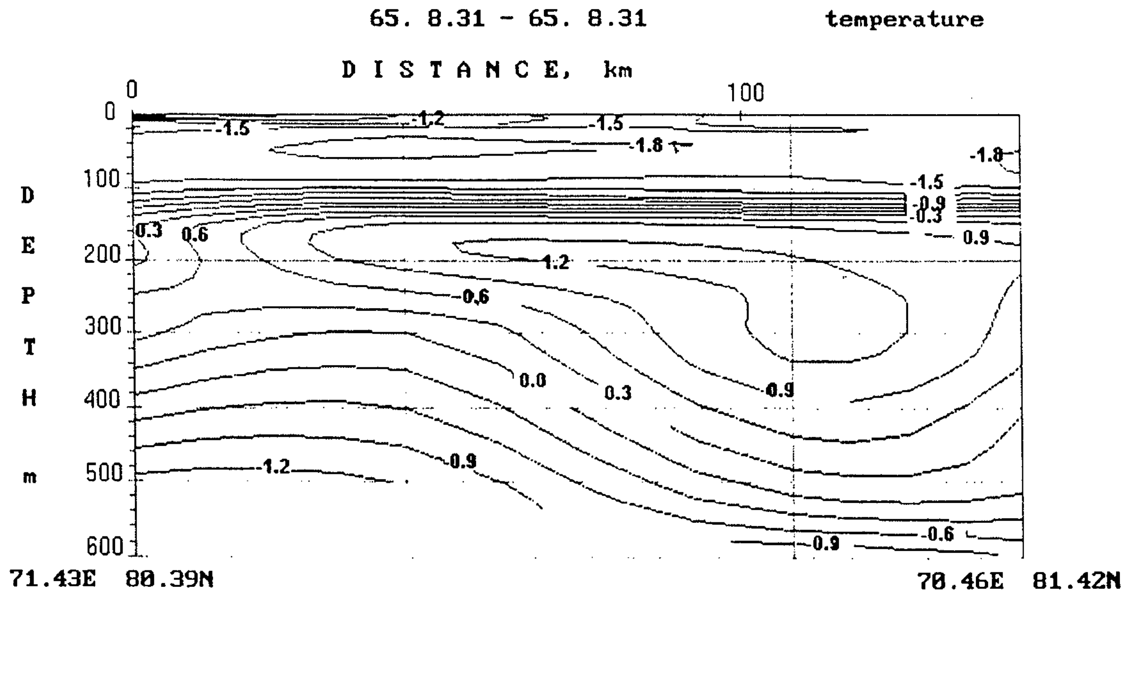

Fig. 7. The summer meridional temperature section, 1965.

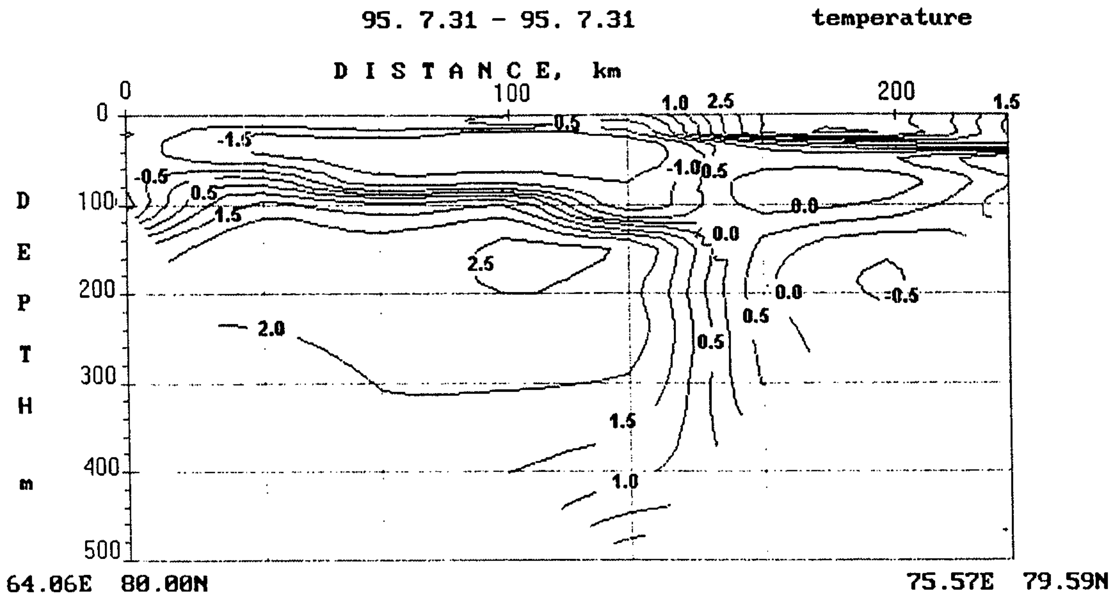

Fig. 8. The summer latitudinal temperature section along 80° N, 1995.

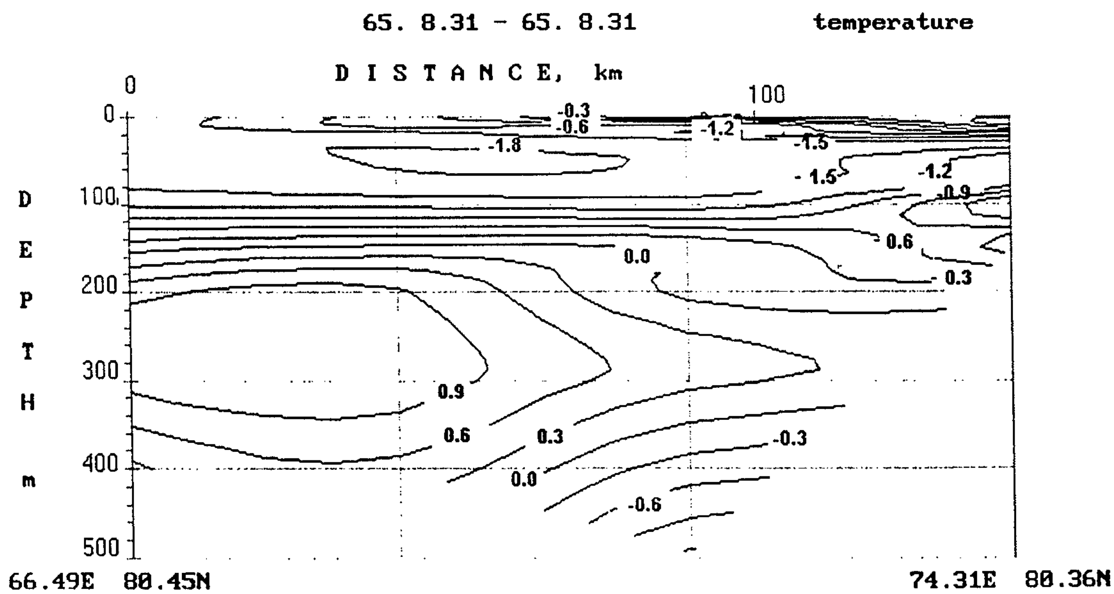

Fig. 9. The summer latitudinal temperature section along 80.5° N, 1965.

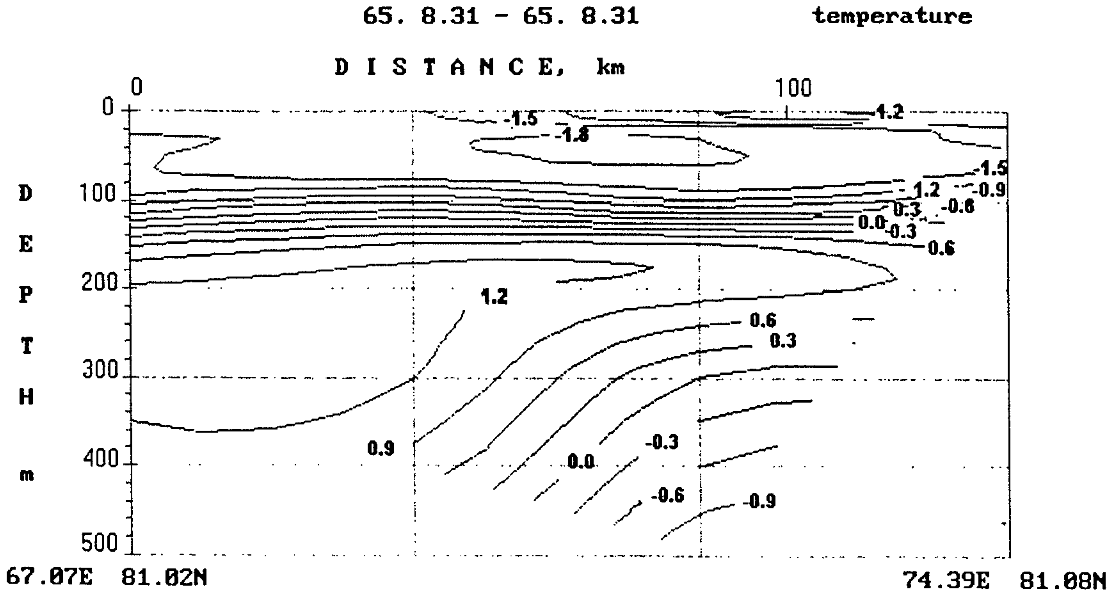

Fig. 10. The summer latitudinal temperature section along 81° N, 1965.

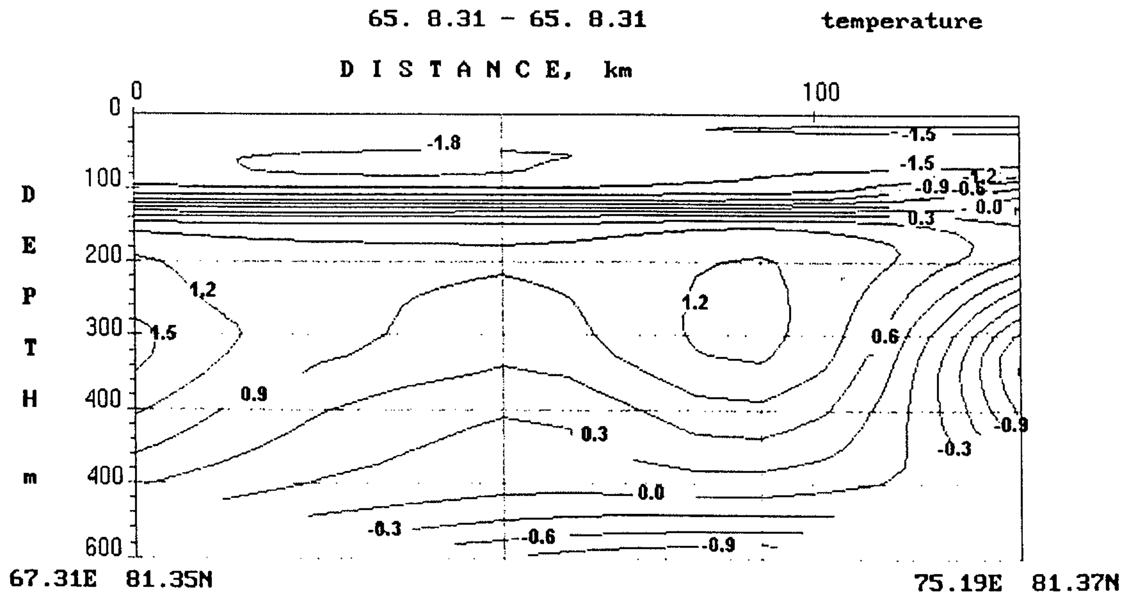

Fig. 11. The summer latitudinal temperature section along 81.5° N, 1965.

We calculated the sound speed using the latest version of Millero's formula [5]. The typical, maximal, and minimal values of temperature (T), salinity (S), and sound speed (V) at the standard horizons are given in Tables 1 and 2 for summer and winter respectively. Note that the extreme values of the sound speed have been determined for the extreme values of temperature and salinity at each horizon (at the upper horizons 0 - 50 m, the maximal sound speed at maximal temperature and minimal salinity, and vice versa for the minimal sound speed). Therefore, the vertical profiles with the minimal and maximal sound speed cannot be regarded as possible real profiles. These extreme values only demonstrate possible variations in the sound speed at different depths. The typical vertical sound speed profiles and the greatest variations of the sound speed observed in the region of the St. Anna Trough in the summer and winter time, are demonstrated in Figures 12a and 12b respectively.

The results presented in the tables and figures, show that:

1. The water temperature in the upper layer 0-100 m is very changeable in summer, which correlates with unstable ice conditions affected by synoptic and interannual variations in the extent of the ice. The ice cover screens the water from the influence of seasonal and synoptic changes in the atmosphere, while the absence of ice leads to fast warming of the upper water layers in summer.
2. The water in the deeper layers may be considerably colder than it is usually, which is due, possibly, to the intrusions of the overcooled and dense Arctic water which flows down from the shallow coastal shelf zone and occupies the lower ocean layers. The evolution of such intrusions depends on the weather and ice conditions in the region.

Table 1. The typical, maximal, and minimal values of temperature, salinity, and sound speed at the standard horizons in the St. Anna Trough in summer.

Depth, m	T_{min}, C°	T_{typ}, C°	T_{max}, C°	S_{min}, psu	S_{typ}, psu	S_{max}, psu	V_{min}, m/s	V_{typ}, m/s	V_{max}, m/s
0	-1.60	-1.40	2.90	27.50	32.50	33.40	1431.48	1439.21	1459.89
25	-1.60	-1.40	1.90	32.80	33.45	34.20	1439.06	1440.90	1457.00
50	-1.75	-1.70	0.25	33.29	34.35	34.63	1439.41	1441.09	1450.59
75	-1.71	-1.70	1.00	33.95	34.45	34.80	1440.90	1441.63	1454.61
100	-1.60	-0.75	1.80	34.42	34.55	34.81	1442.47	1446.67	1458.58
150	-0.30	0.90	2.50	34.60	34.75	34.90	1449.64	1455.31	1462.57
200	-0.10	1.50	2.50	34.74	34.83	34.93	1451.56	1458.91	1463.42
300	-0.75	1.65	2.25	34.81	34.91	34.99	1450.25	1461.31	1464.05
500	-1.34	1.20	1.37	34.78	34.94	34.95	1450.68	1462.63	1463.40

Table 2. The typical, maximal, and minimal values of temperature, salinity, and sound speed at the standard horizons in the St. Anna Trough in winter.

Depth, m	T_{min}, C°	T_{typ}, C°	T_{max}, C°	S_{min}, psu	S_{typ}, psu	S_{max}, psu	V_{min}, m/s	V_{typ}, m/s	V_{max}, m/s
0	-1.87	-1.86	-1.86	33.69	33.90	34.07	1438.57	1438.91	1439.14
25	-1.87	-1.85	-1.85	33.86	34.10	34.13	1439.21	1439.63	1439.67
50	-1.80	-1.70	-1.60	34.03	34.30	34.32	1440.18	1441.02	1441.53
75	-1.71	-1.70	-1.42	34.20	34.45	34.45	1441.24	1441.63	1442.97
100	-1.60	-0.75	1.80	34.42	34.55	34.81	1442.47	1446.67	1458.58
150	-0.30	0.90	2.50	34.60	34.75	34.90	1449.64	1455.31	1462.57
200	-0.10	1.50	2.50	34.74	34.83	34.93	1451.56	1458.91	1463.42
300	-0.75	1.65	2.25	34.81	34.91	34.99	1450.25	1461.31	1464.05
500	-1.34	1.20	1.37	34.78	34.94	34.95	1450.68	1462.63	1463.40

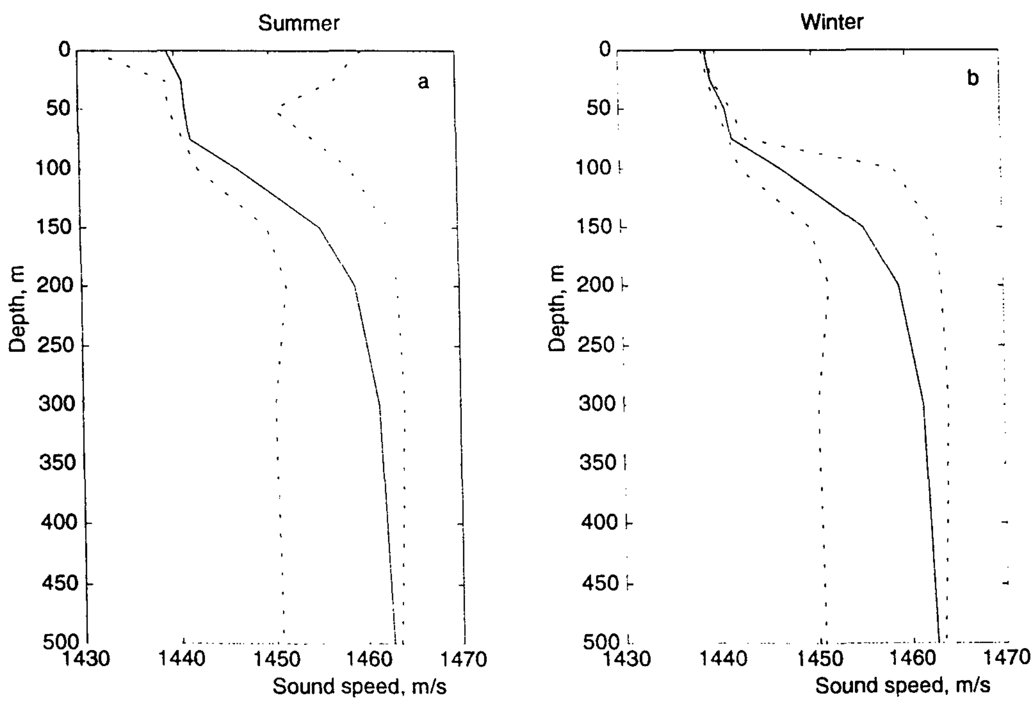

Fig. 12. Typical sound speed profiles (solid) and extreme variations of the sound speed at different depths (dashed) in the St. Anna Trough in summer (a) and winter (b).

III. FRANZ VICTORIA TROUGH

3.1. Data

For the analysis, we used the WOA-94 data (22 profiles) and the CTD profiles measured by the authors during polar expeditions in the Franz Victoria Strait. We selected the CTD profiles located within the coordinates 81-83° N, 38-45° E and which passed the test for reasonable deviations relative to the mean-month and mean-season values. The CTD profiles in the shallow water region (a 50 km zone south of 81.5° N, 38° E - 82.5° N, 45° E, sea depth of 400-500 m) as well as those over the continental slope (deep water), were analyzed separately.

Unfortunately, the CTD data of recent expeditions in the Franz Victoria Strait (Oden-91, and some others) are not yet available to the authors, and, therefore, have not been included in the analysis in this report.

3.2. Results

The T-S analysis of the CTD data was carried out in the same way as that of the CTD data in the St. Anna Trough. According to the climatology data on the extent of the ice cover [6], the most probable extent of the ice pack in the Franz Victoria Trough, in both the summer and winter, ranges further south than the region considered. However, the margin of the smallest extent of the ice pack in summer, in some years, may be located north of the region. This causes seasonal variations of the water temperature in the upper layers, from the surface to a depth of about 100 m. Therefore, one should analyze the hydrological characteristics in this region for summer and winter conditions, separately.

Tables 3 and 4 present the typical, maximal, and minimal values of temperature (T), salinity (S), and sound speed (V) at the standard horizons in the shallow water part of the region, in summer and winter, respectively. The typical sound speed profiles and possible variations at different horizons in the northern part of the Franz Victoria Trough, in summer and winter, are shown in Figures 13a and 13b, respectively.

As in the St. Anna Trough, the temperature of the water in the upper layer strongly varies in the summer time (or from summer to summer), which correlates with the extent of the ice. The Atlantic water core in the Franz Victoria Trough is shallower (100-200 m) than in the St. Anna Trough, and appears thinner and less warm. This supports the concept, that the St. Anna Strait is, perhaps, one of the primary channels (besides the Fram Strait) for Atlantic water transport in the deep Arctic Basin [7].

The water temperature in the deeper ocean layers in the Franz Victoria Trough is unstable in summer as well as in winter. The origin of the temperature variations, here, is similar to that in the St. Anna Trough. The interaction and meeting of the warm Atlantic water and cold shelf water lead to strongly predictable, seasonally independent changes in the deep waters. The spatial scale and dynamics of the cold water intrusions are rather poorly studied. The cold shelf water spreads at a depth from 50-100 m to 400-500 m, according to its density. The intrusions may cover an extensive area, reaching the deep water basin. This is clearly seen in Figure 14 which shows typical sound speed profiles, and possible variations of the sound speed, at different horizons over the continental slope, north of the Franz Victoria Trough. Such intrusions may reduce the temperature in the Intermediate layer of Atlantic water by 2° C (10 m/s in sound speed), relative to the typical values.

Table 3. The typical, maximal, and minimal values of temperature, salinity, and sound speed at the standard horizons in the northern part of the Franz Victoria Trough in winter.

Depth, m	T_{min}, C°	T_{typ}, C°	T_{max}, C°	S_{min}, psu	S_{typ}, psu	S_{max}, psu	V_{min}, m/s	V_{typ}, m/s	V_{max}, m/s
0	-1.9	-1.8	-1.7	33.0	33.5	34.0	1438.5	1438.6	1439.8
25	-1.9	-1.8	-1.7	33.0	33.8	34.0	1438.9	1439.5	1440.2
50	-1.9	-1.6	-1.7	34.0	34.4	34.5	1440.6	1441.6	1442.2
75	-1.5	-0.5	1.8	34.5	34.6	34.8	1442.7	1447.5	1457.7
100	-0.8	0.5	2.0	34.7	34.7	34.	1446.7	1452.6	1459.3
150	0.3	1.7	2.1	34.8	34.8	34.	1452.7	1458.9	1460.7
200	0.1	1.2	1.8	34.8	34.9	34.9	1452.6	1457.6	1460.2
250	0.0	0.5	1.9	34.8	34.9	34.9	1452.9	1455.3	1461.4
300	0.0	0.3	1.8	34.8	34.9	35.0	1453.7	1455.2	1461.8
400	-0.5	-0.1	0.5	34.8	34.9	34.9	1453.0	1455.0	1457.6

Table 4. The typical, maximal, and minimal values of temperature, salinity, and sound speed at the standard horizons in the northern part of the Franz Victoria Trough in summer.

Depth, m	T_{min}, C°	T_{typ}, C°	T_{max}, C°	S_{min}, psu	S_{typ}, psu	S_{max}, psu	V_{min}, m/s	V_{typ}, m/s	V_{max}, m/s
0	-1.8	-1.0	-0.7	32.0	32.8	33.2	1438.2	1441.5	1441.8
25	-1.9	-1.2	-0.8	33.2	33.4	34.3	1439.6	1441.7	1443.4
50	-1.7	-1.5	1.2	34.4	34.4	34.8	1441.1	1442.1	1455.1
75	-1.5	-0.5	1.8	34.5	34.6	34.8	1442.6	1447.5	1458.1
100	-0.8	0.8	2.0	34.7	34.7	34.8	1446.6	1453.9	1459.4
150	0.3	1.7	2.1	34.8	34.8	34.9	1452.6	1458.9	1460.8
200	0.1	1.2	1.8	34.8	34.9	34.9	1452.5	1457.6	1460.3
250	0.0	0.5	1.9	34.8	34.9	34.9	1452.9	1455.3	1461.5
300	0.0	0.3	1.8	34.8	34.9	35.0	1453.7	1455.2	1462.0
400	-0.5	-0.1	0.5	34.8	34.9	34.9	1453.0	1455.0	1457.7

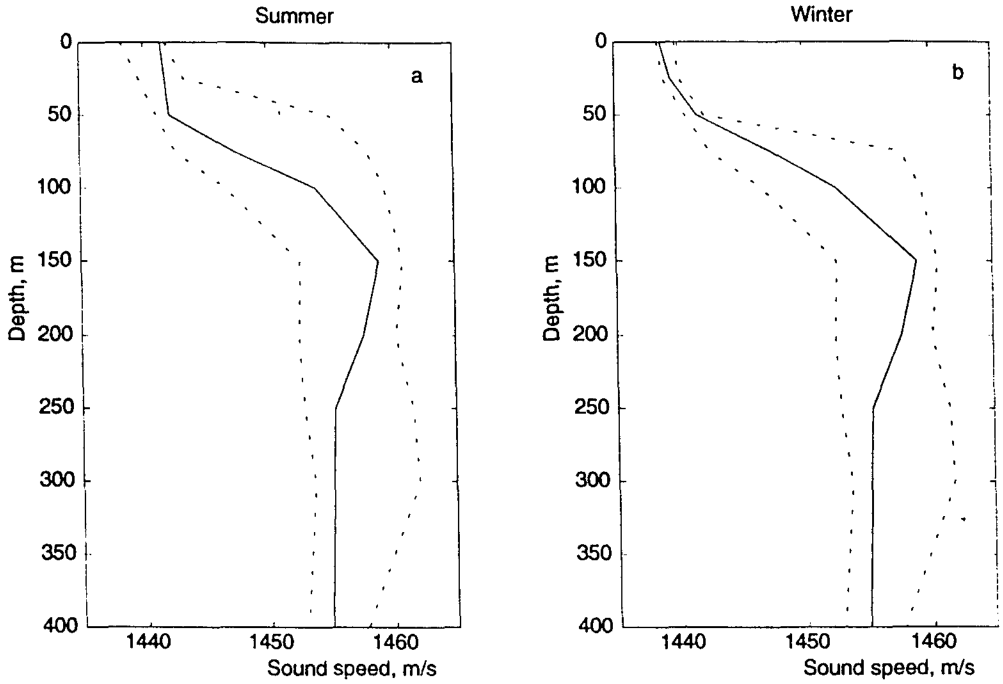

Fig. 13. Typical sound speed profiles (solid) and extreme variations of the sound speed at different depths (dashed) in the northern part of the Franz Victoria Trough in summer (a) and winter (b).

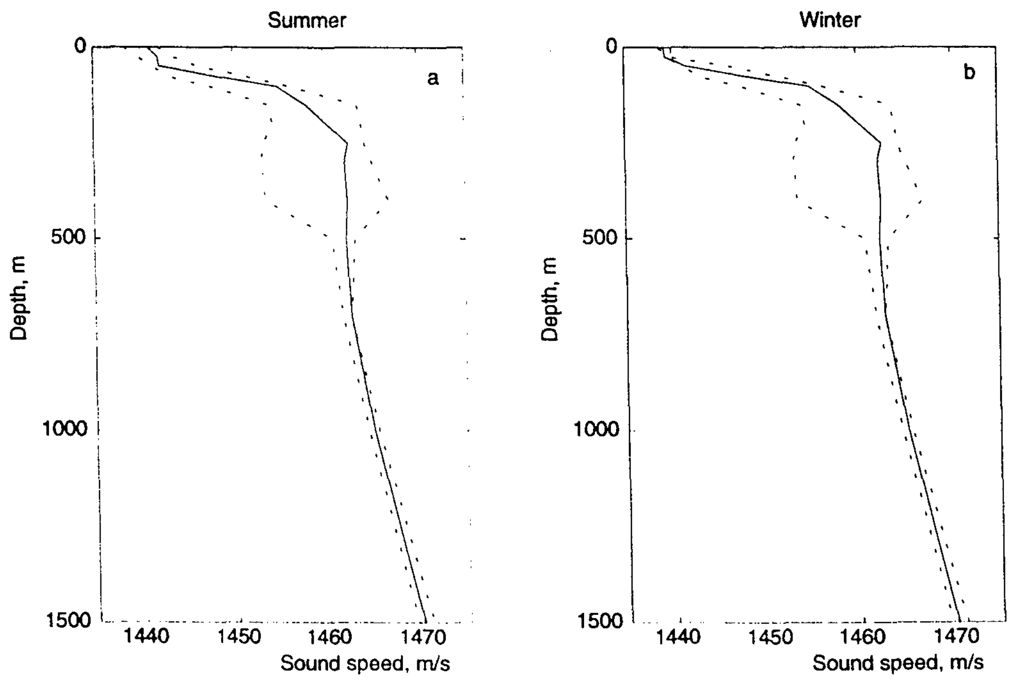

Fig. 14. Typical sound speed profiles (solid) and extreme variations of the sound speed at different depths (dashed) over the continental slope north of the Franz Victoria Trough in summer (a) and winter (b).

IV. CONCLUSION

The CTD data available for the northern parts of the St. Anna and Franz Victoria Troughs, are considered in this Report. The analysis of the data has shown that the T-S structure and the sound speed in these regions are subject to considerable variations. In the summer time the water temperature in the upper mixed layer varies, correlating with the condition of the ice cover which is unstable due to perturbations of climatic and synoptic origins.

The water temperature in the deeper ocean layers in the troughs changes considerably in both the summer and winter periods. The main reason for those changes is the interaction of the warm Atlantic water passing through the straits, with the cold coastal shelf water flowing down to the troughs. The origin and evolution of the shelf waters depend on synoptic and ice conditions in the regions.

The data and the results obtained in this work will be used for the analysis of acoustic propagation characteristics related to year-round acoustic thermometry at the transarctic paths: FJL - Lincoln Sea and FJL - Beaufort Sea, in the framework of the contract.

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